The Measurement Problem

In Part III are the following few paragraphs:

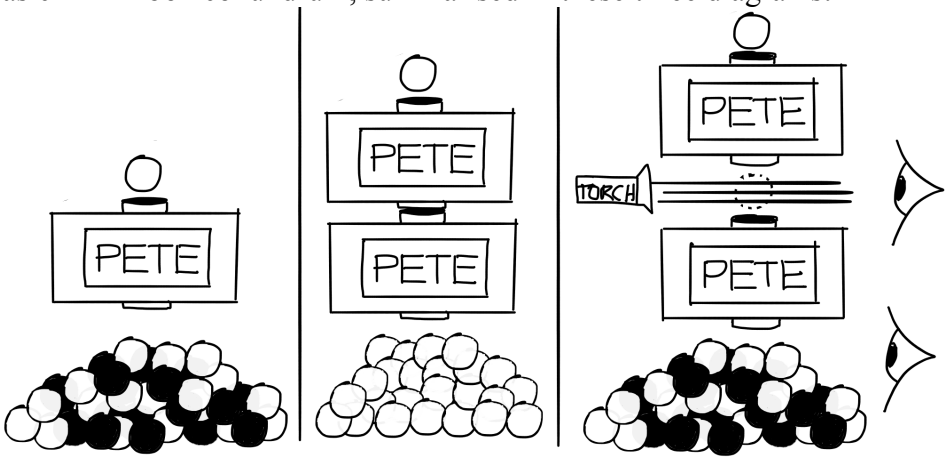
To make matters worse, the laws demand that the collapse only ever happens when an observer, such as you or I, looks at the color of the ball. As we considered in Part I, we might employ a wide variety of different techniques to try to observe the ball's color in different ways, some more gentle than others. The collapse process doesn't care about the method we use to interact with the ball, it just happens as soon as that method is strong enough to tell us the ball's color, and it doesn't happen at all otherwise.

Does it then matter in this situation whether or not we actually observe the color? What if we use some kind of unintelligent observing device to probe the ball between the boxes, but we do not look at the color recorded on the device? What we have done is create a really large misty state. The mist representing the ball is now entangled with the mist representing the stuff making up the device. It is this entanglement which causes the "disturbance" to the ball which is responsible for the fact it no longer always falls from the second PETE box the same color it entered the first. However, the actual collapse, the laws claim, only happens when you, the observer, look at this large misty state, either indirectly by reading the device or more directly just looking at the ball. Then the ball mist collapses into "black" or "white" and the observation-device mist collapses into a "black" or "white" reading.

Why should observers be so important? Why should the widely different physical mechanisms they use to interact with the ball make no difference to the final real state the ball ends up in, or how that process occurs?

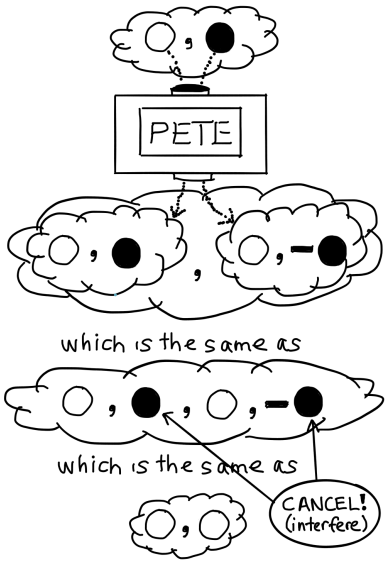
At that point I felt it would too much of a digression to get into a more detailed explanation of this topic, which is commonly known as "the measurement problem". But by this stage you have actually acquired enough technical prowess to understand the measurement problem quite precisely.

Recall the basic PETE-box conundrum, summarised in these three diagrams:



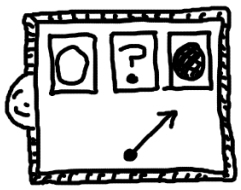
Focus on the rightmost diagram. If we observe the color of the ball after the first PETE box, then we destroy the mist, and we see the color of the ball, black or white with equal likelihood. Once we have observed the ball we know the color it enters the second PETE box. The ball then exits

the second PETE box in either the misty state [W,B] or the misty state [W,-B]. Thus, when we observe the ball the second time we again see the ball randomly either black or white, with equal likelihood. Here is the calculation of the mist entering the second PETE box that I showed you in Part I:

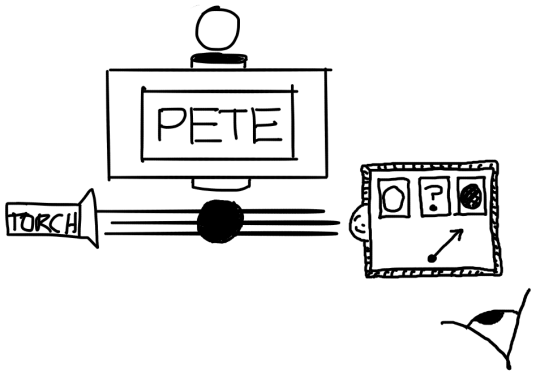


The rule associated with process of changing the mist we use to describe the ball once we make an observation is called *collapse*, and is discussed extensively in Parts II and III.

How important is it that you, a (hopefully) intelligent human, make the observation of the ball's color? Imagine we build a measuring device which can observe the color of the ball. The device has a pointer that either points to a label reading out the color of the ball, or to a label indicating it does not know the ball's color.



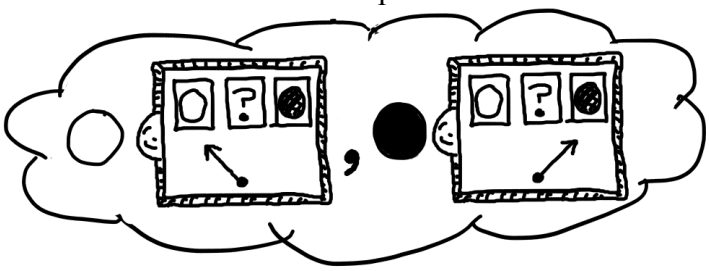
We let it interact with the ball in-between the two PETE boxes in such a way that it can record the color:



If we look at the device, we know the color of the ball – we have done an indirect measurement (via the device) of the ball's color. Nothing changes from the case where we observe the ball more directly—if we then send the ball into a second PETE box it emerges a random color. That is,

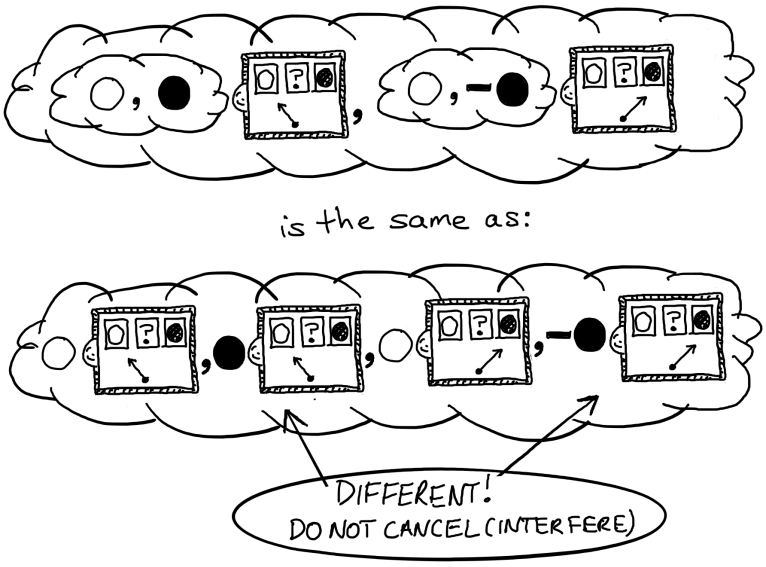
whether we did the measurement directly or indirectly doesn't matter, the interference does not occur because we have destroyed the mist by learning what the color is after the first PETE box.

What happens if we do not look at the measurement device? That is, we let the measurement device record the ball's color, but we do not look at the measurement device. The laws of misty physics dictate that the measurement device also becomes part of the mist:



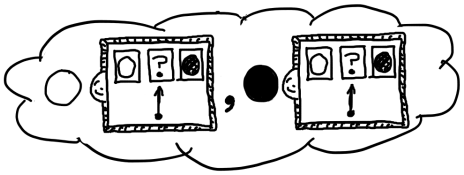
Note that within the mist the measurement device appears in two distinct physical states – one in which the pointer indicates the ball is white, one in which the pointer indicates the ball is black.

Imagine we now send the ball through a second PETE box, still without us looking at either the ball or at the measuring device. The measurement device is unaffected, but the ball splits into [W,B] and [W,-B] mists in the standard manner:

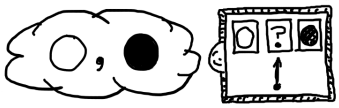


The key point here is that the two configurations involving the ball being black are no longer identical because the two measurement device states are distinct; they no longer interfere. This means the two configurations containing the ball being black do not disappear, they remain in the mist. As such, even if we do not ever observe the measuring device, the ball will come out the second PETE box randomly black or white. The measuring device became entangled with the ball, and that entanglement inhibited the interference.

If the measuring device was not able to determine the ball's color, then we would have ended up with the mist:



which is the same as:

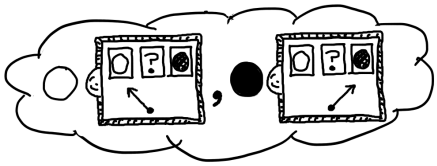


and this is not entangled, the ball stays in the [W,B] mist as normal, and the interference still occurs.

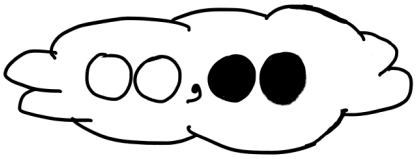
Once you have seen this, it becomes tempting to say "this distinction between humans and physical measuring devices is nonsense. Either (i) we should find a way to describe measuring devices so that they collapse mists just like humans do or (ii) we should find a way to describe humans so they do not collapse mists just like measuring devices do."

The *measurement problem* is basically that either of those option leads to radically different descriptions of the world, and each has its own challenges.

Option (i) requires being able to extract from the physics some way to decide the special point at which it is no longer valid to construct a mist like:



Since we know that we are able to construct mists like:

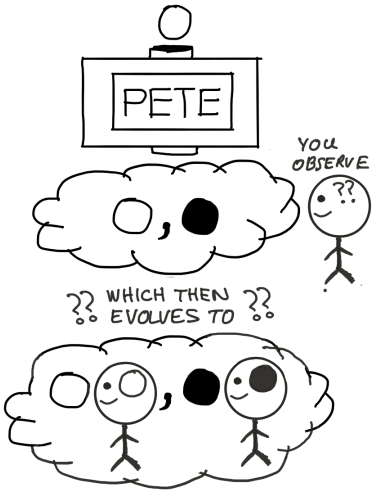


we know that a second ball can be an "entangled measuring device" with the first ball. So option (i) means we would have to understand the distinction in complexity between a measuring device and a ball, and how it is that only mists containing devices of a certain size/complexity collapse and so on.

Option (ii) was also mentioned briefly in Part III. Quoting from there:

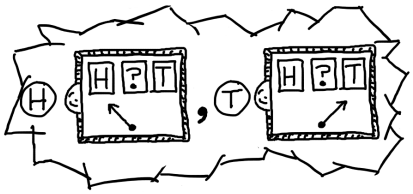
Option (ii) is more subtle—it typically involves thinking about the absolutely giant misty state that makes up everything in the universe including the observers of the balls, and denying that this giant misty state ever collapses. The challenge then is to extract an explanation of how the very small pieces of that giant mist that comprise you and me experience a world where we can talk about little mists of one and two balls, little mists that give random outcomes when we observe them; a world where the assumption of collapse works so well. (This is often called "the measurement problem.") The most studied option along these lines has been to assume that the

giant mist actually describes many different universes, and when you observe the misty state of a single ball there are actually two copies of you created, one that lives in a universe where the ball you observe is white and one where it is black:



It is a dramatically different view of all of physical reality.

There is a third way—which is to say that its perfectly fine to have a distinction between humans and measuring devices, so there is no problem. Advocates of this view are saying that misty states are states of knowledge, analogous to rocky states. If you build a measuring device that can determine the state, Heads or Tails, of a flipped coin then you are presumably comfortable with describing the state of the coin and a measuring device which has "observed" the coin via the rocky state:



You are also presumably comfortable with saying that the rocky state changes (that is, collapses) when you observe the device because it was only ever a mathematical tool to represent your state of knowledge, your information, about the coin and measuring device. The measuring device doesn't collapse the state because it isn't a device that thinks, processes information etc. All this seems very pertinent to the similar description of misty states. In Part III I discussed in more detail the challenges that this third way faces. We saw that the two main paths followed along this third direction either try to extract a description of physical reality without recourse to the notion of "physical properties" and real states and so on, or are forced into very disconcerting and strange (for a curmudgeonly old physicist like me) behavior of the systems and their associated physical properties (nonlocality, no preparation independence and the suchlike).